Radio-Frequency Radiation Safety Programs

2007 NASA Occupational Health Conference

Denver, Colorado

July 25, 2007

RF Safety Programs (RFSP)

- IEEE C95.1-2005 states:

"Where there may be access to RF fields, currents and/or voltages that exceed the lower tier (Action Level) of this standard, an RF safety program such as detailed in IEEE Std C95.7-2005 shall be implemented …"

Why implement a RFSP?

- Protect human health (ethical and moral considerations)
- Reduce liability
- Reduce potential for negative publicity
- Reduce insurance costs

IEEE RP C95.7-2005

- Basis of a RF safety program (RFSP)

- Establishes action level
  - Lower tier of IEEE Std C95.1
  - ICNIRP general public guidelines
  - 1/5th ACGIH TLVs
  - FCC uncontrolled/general public limits

IEEE Std C95.1-2005

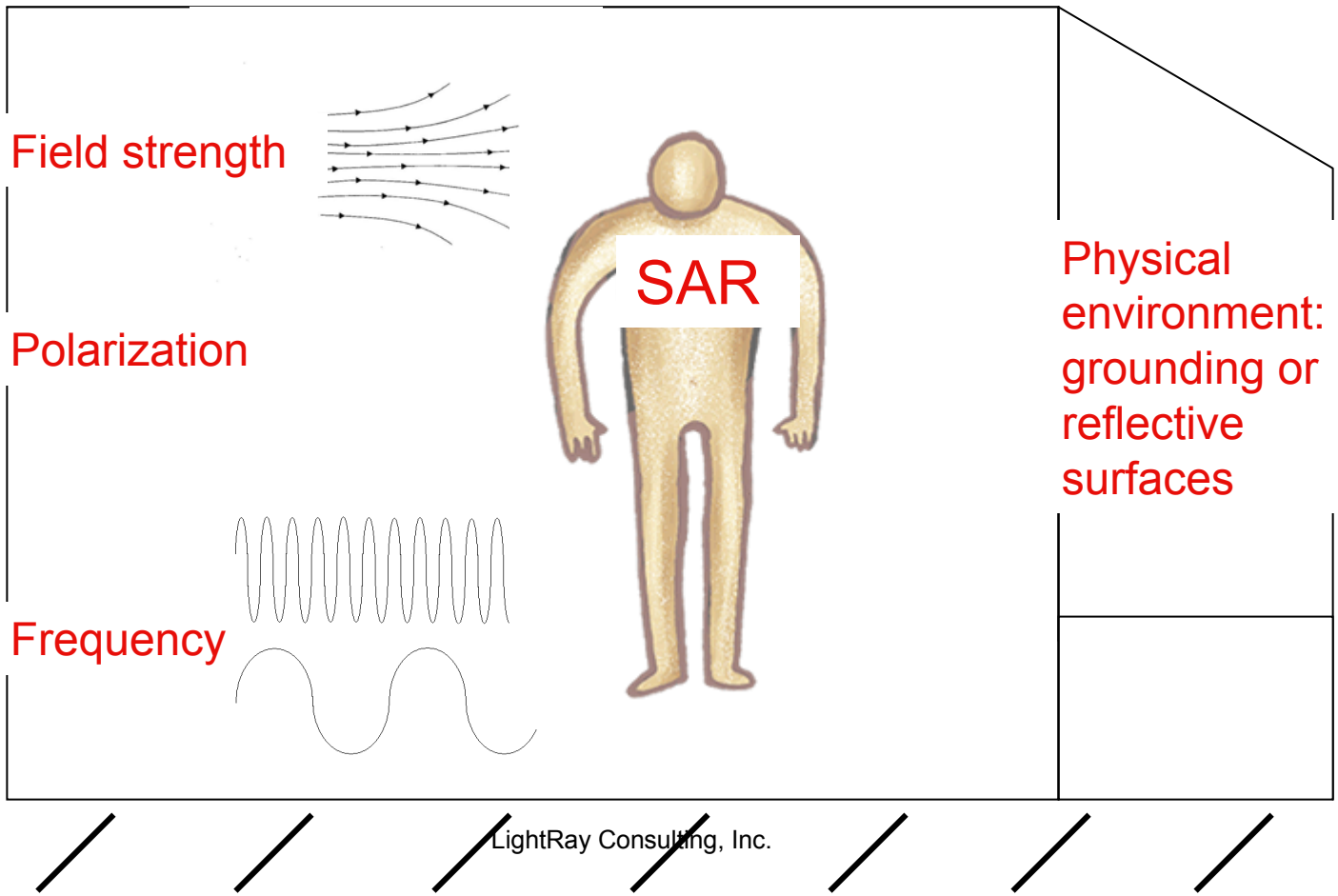
- Covers 3 kHz to 300 GHz
- Defines basic restrictions (dosimetric quantities) for 3 regions
- Defines 2 tiers of exposure guidelines
  - Lower tier – general public or action level
  - Upper tier – controlled environment

Basic Restrictions

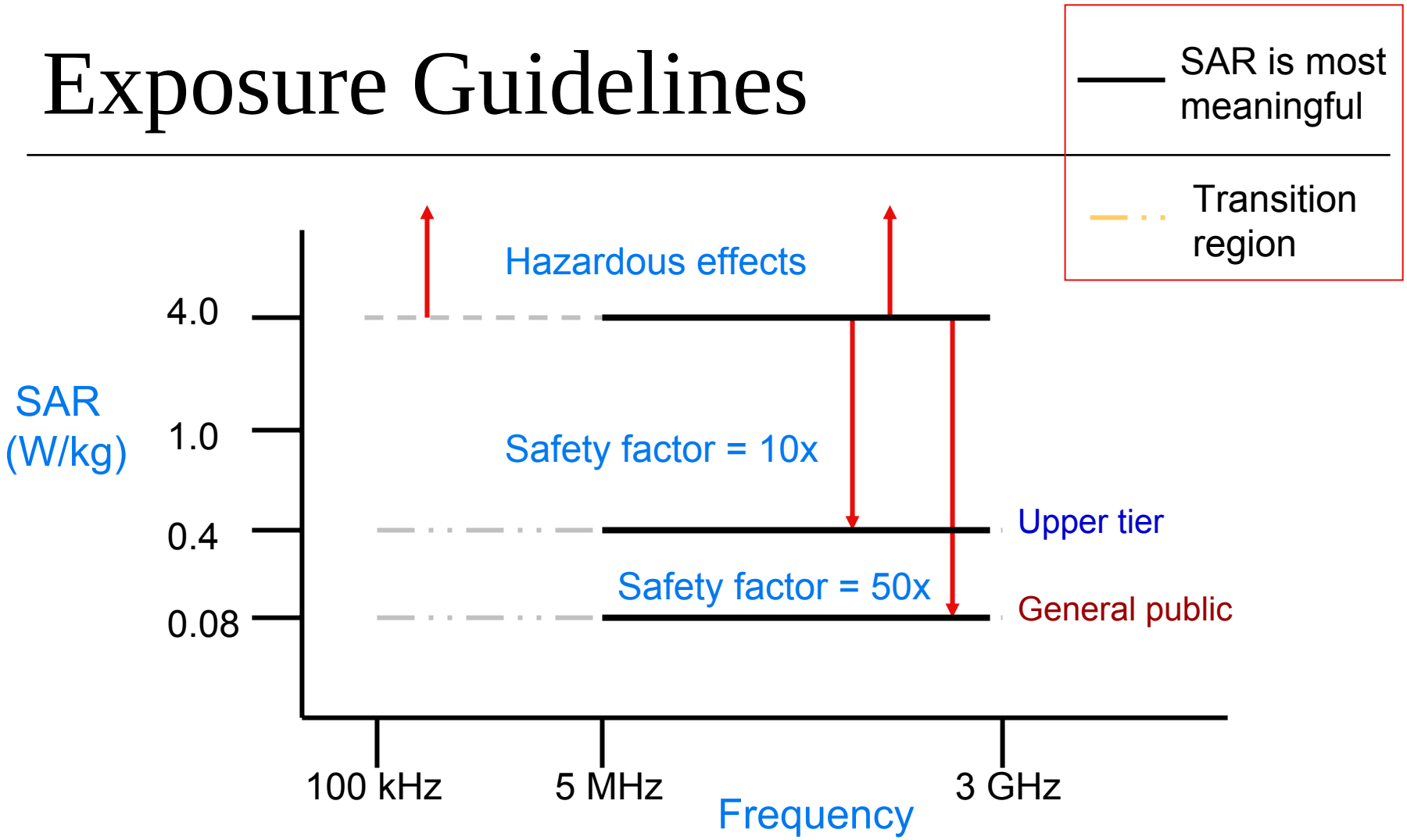
Region	Frequency	Dosimetric Quantity
Electrostimulation	3 kHz-5 MHz	*in situ* E field
Adverse heating	100 kHz-3 GHz	SAR
	3 GHz-300 GHz	Power density
Transition	100 kHz-5 MHz	*in situ* E field; SAR

Determinants of Absorption

SAR = dose rate (W/kg)



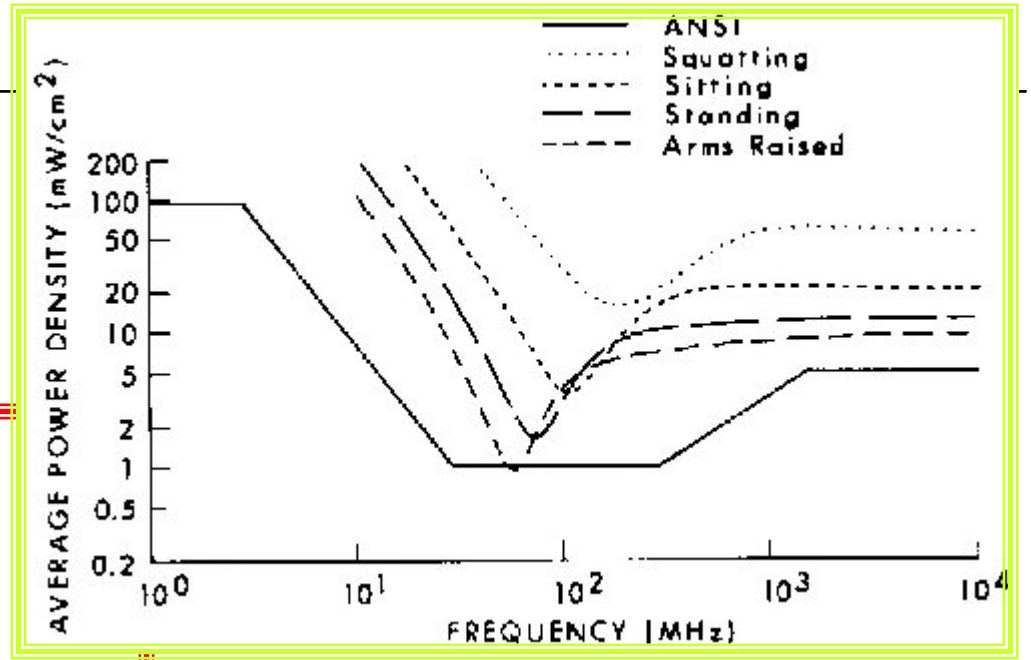
Exposure Guidelines

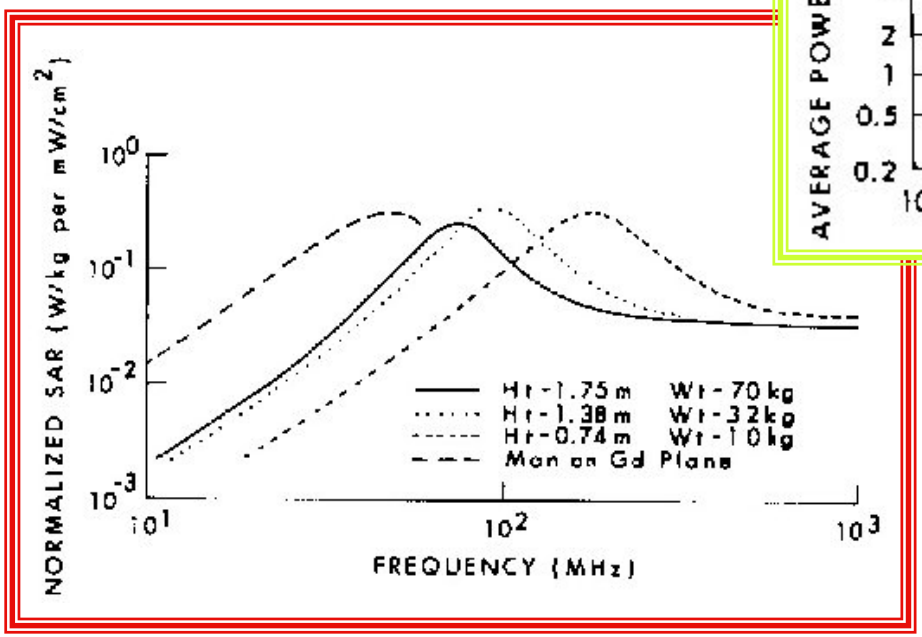


Upper tier = controlled environment

Whole-body Resonance

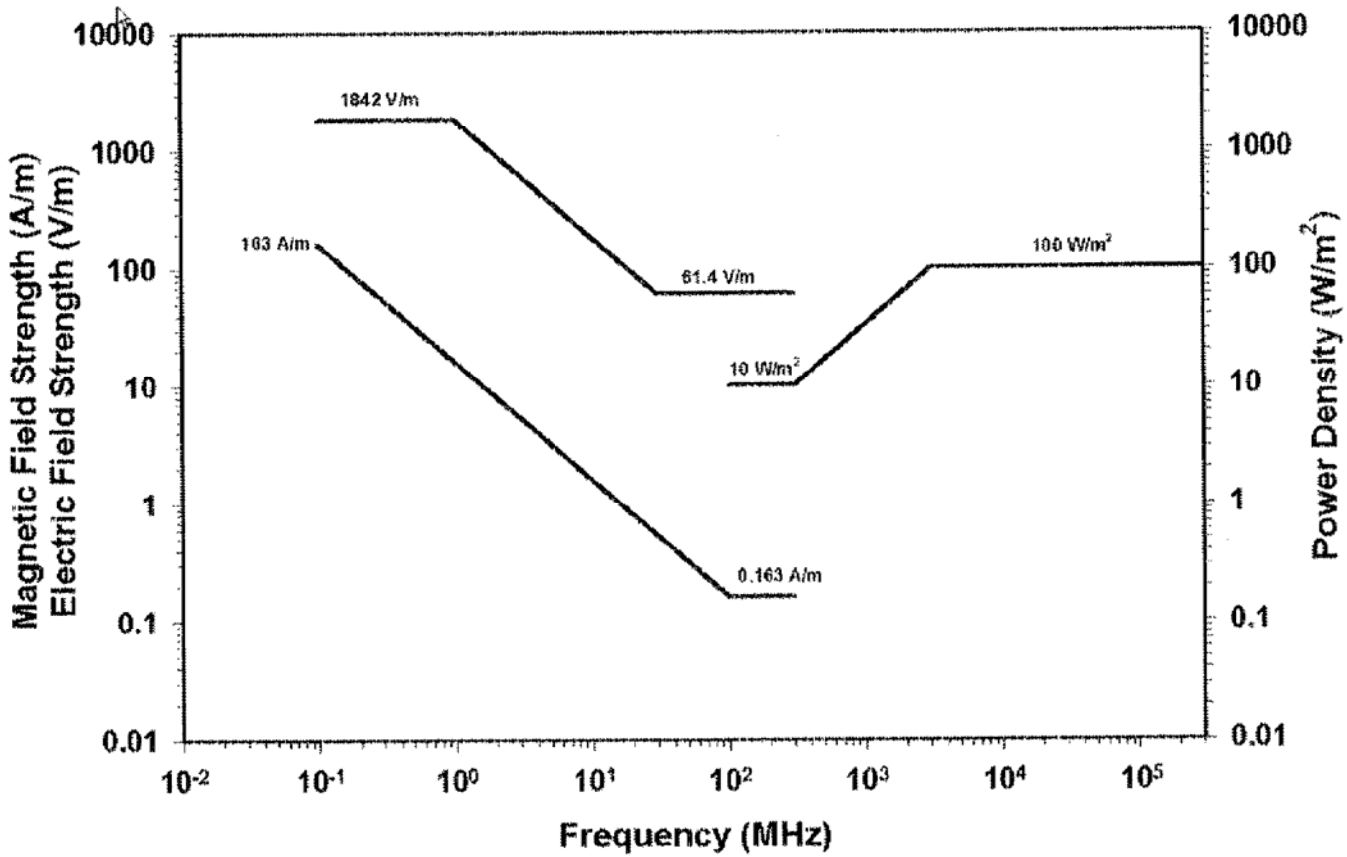
- Frequency dependent
- Varies with body height & girth





- Basis for 5-region envelope exposure curve
- Biological basis (magnitude of limits): reversible behavior disruption

MPEs: Upper Tier



MPEs: General Public

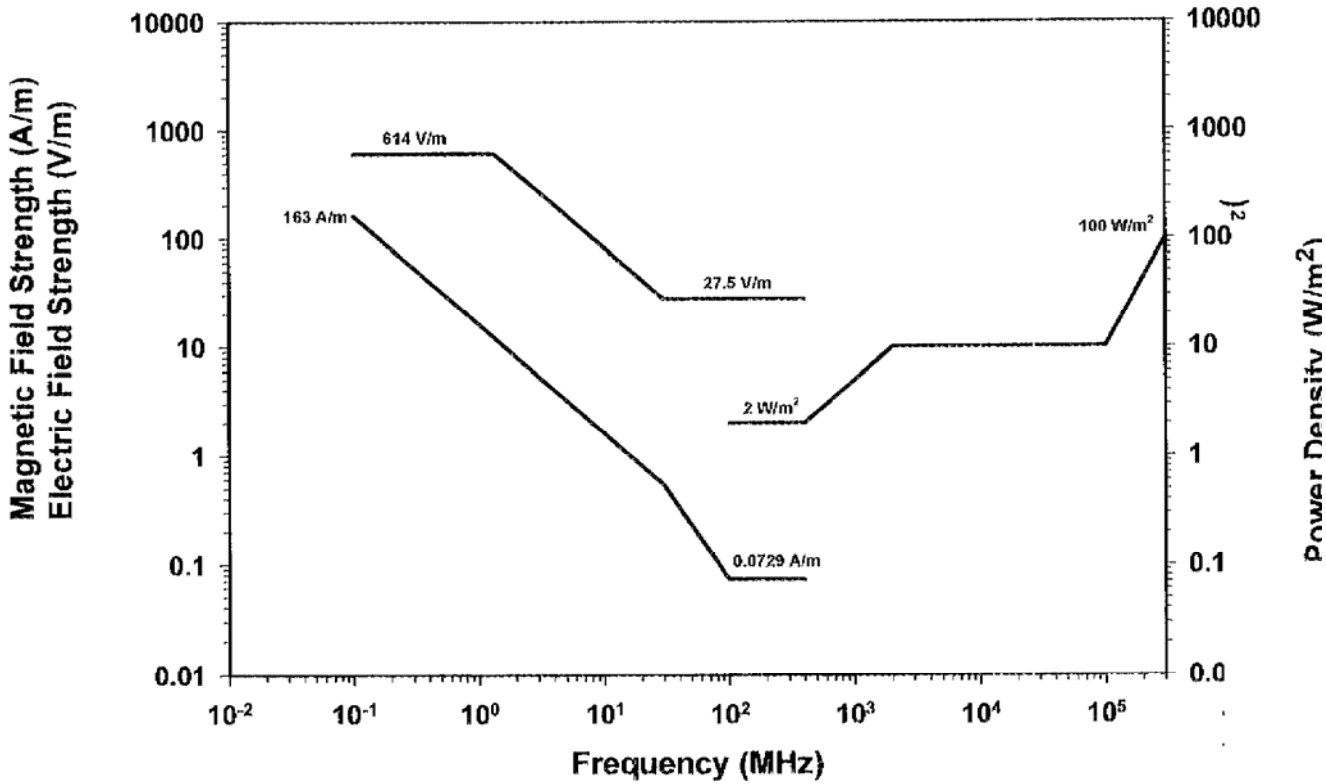


Figure 4—Graphic representation of the MPEs in Table 9 (lower tier—action level)

Biological & Health Effects

	Test Animal	Human Study
Behavior	Acute effects in learned and innate behavior. Reversible disruption in non-human primates at 3.2 to 4 W/kg.	Not conclusively demonstrated. Reported in Russia & East Europe, 1950's – 1970's. Few reports in US at very high exposure levels.

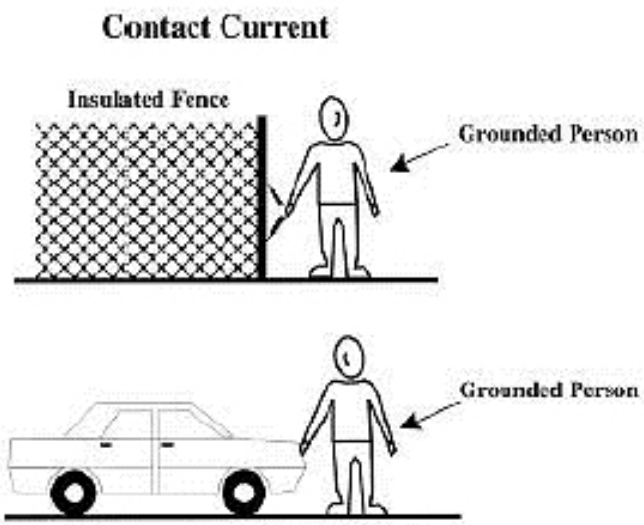
…a measure of the health of the CNS & associated systems …

Subjective Reports of Behavioral Effects

- Moodiness
- Irritability
- Unsociability
- Disturbed sleep
- Feelings of fear
- Mental depression

…these are also observed in members of the general population who have no remarkable exposure to RFR …

Low-Frequency Exposure



- Low-frequency RF currents may generate heat, burns or shock
- Contact & induced current limits: 3 kHz and 110 MHz

Electrostimulation: Bioeffects

- Aversive or painful stimulation of sensory or motor neurons
- Muscle excitation leading to injury
- Cardiac excitation
- Excitation of neurons or direct synaptic activity within the brain

Induced & Contact Current Limits

Frequency	Condition	Action Level (mA)	MPE (mA)	Averaging Time (s)
3 – 100 kHz	Both feet	0.90f	2.00f	0.2
	Each foot	0.45f	1.00f	
	Contact, grasp	None	1.00f	
	Contact, touch	0.167f	0.50f	
0.1 – 110 MHz	Both feet	90	200	360
	Each foot	45	100	
	Contact, grasp	None	100	
	Contact, touch	16.7	50	

Elements of RFSP

- Written policy or operating procedure
- Name RF safety officer, RFSO
- Inventory Sources
- Perform exposure assessment
- Categorize work locations

RFSP Categories

RFSP Category	Exposure Condition	Control Actions Required
1	Action level not exceeded.	None, unless maintenance or other conditions alter category.
2	Exposure limit not exceeded.	Various.
3	Potential to exceed OEL.	Various.
4	OEL will be exceeded.	Restrict source output to achieve category 3, 2, or 1 or prevent access.

IEEE C95.7

- RFSP not required for Category 1 if
  - Levels < action level during operation, maintenance or service
  - RFSO not required

- RFSP necessary for Category 1 if
  - Levels may exceed the action level (i.e., change category) during maintenance or service

17 Duties of RFSO

- Initial evaluation & monitor changes
- Maintain inventory
- Evaluate existing safety procedures
- Document program
- Monitor legal requirements
- Disseminate RF safety policy to organization
- Advice to staff on policy & procedures
- Review/authorize surveys & control measures
- Maintain list of approved RF personnel
- Manage medical assessments for potential exposures potential exp > action level

17 Duties of RFSO

- Coordinate safety awareness training and maintain training records
- Conduct/arrange site audit (every 3 yrs)
- Annual review of policy & procedures
- Manage investigation of breaches of policy & procedures & incidents
- Develop/approve hazard assessment tools
- Arrange for regular calibration of measurement equipment
- Ensure control & archiving of all documentation

Elements of RFSP

- Suggested inventory criteria:
  - Device/type, frequency, radiated power, antenna type (if applicable), summary of potential for RF exposure
  - Annex C provides additional guidance on inventory

What are some sources of RF?

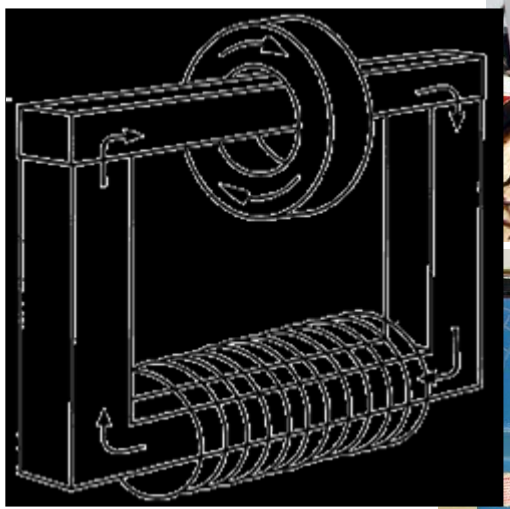
- Dielectric heaters
- Induction heaters
- Communications
- Broadcasting
- Radar
- Plasma processing
- Microwave dryers/heaters
- CRT-type VDTs
- Electrical discharge machines

Dielectric Heater

- Used to heat dielectric materials (nonconductors)
- Majority operate at 27 MHz
- Unshielded units may produce overexposures

Round-table plastic sealer

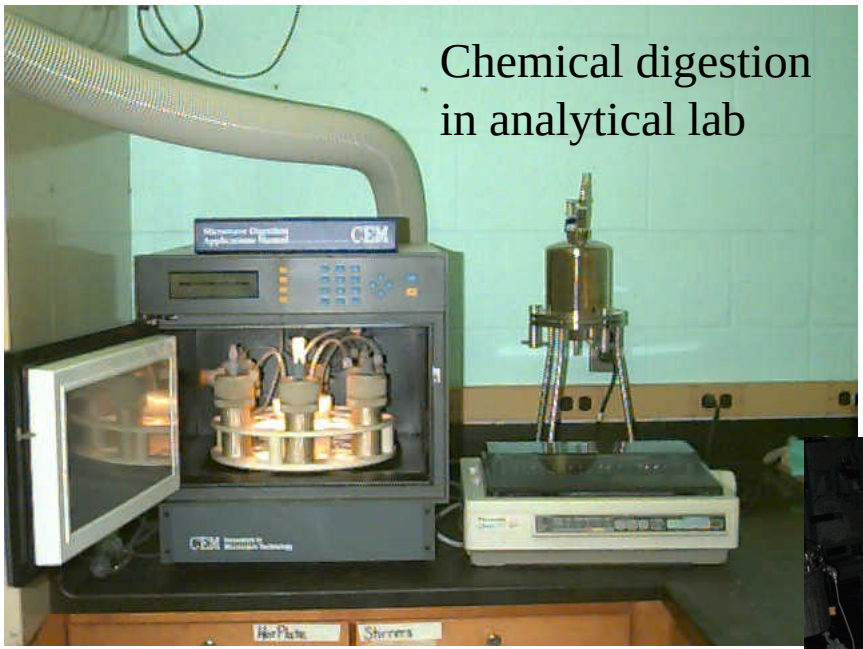
Induction Heaters



Transformer

- Heat conductors
- Part to be heated becomes secondary transformer winding
- Operate at low frequencies
- Frequency depends upon necessary penetration depth

Various Microwave Devices



Chemical digestion in analytical lab

Conveyorized microwave dryers

Various Radiowave Devices

CRT-type
Video
Display Unit

EDM Unit (electrical discharge machine)

Sputtering Unit

Communications

- SATCOM antennas
- Telephony antennas
- Cell phone antennas
- CB radio
- Two-way radio
- High-frequency radio
- Microwave radio
- Tropospheric scatter

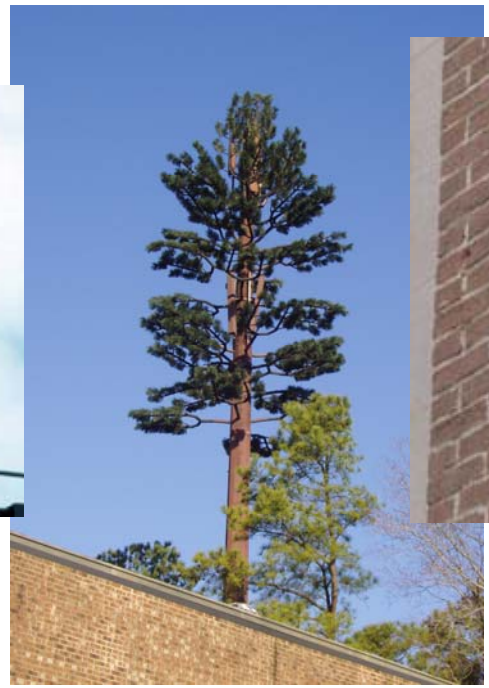
Line-of-Sight Transmission

- Microwave emitters
- Far pix: Long-haul & local telephone traffic
- Near pix: Private microwave link for transmitting data

Cellular Telecommunications

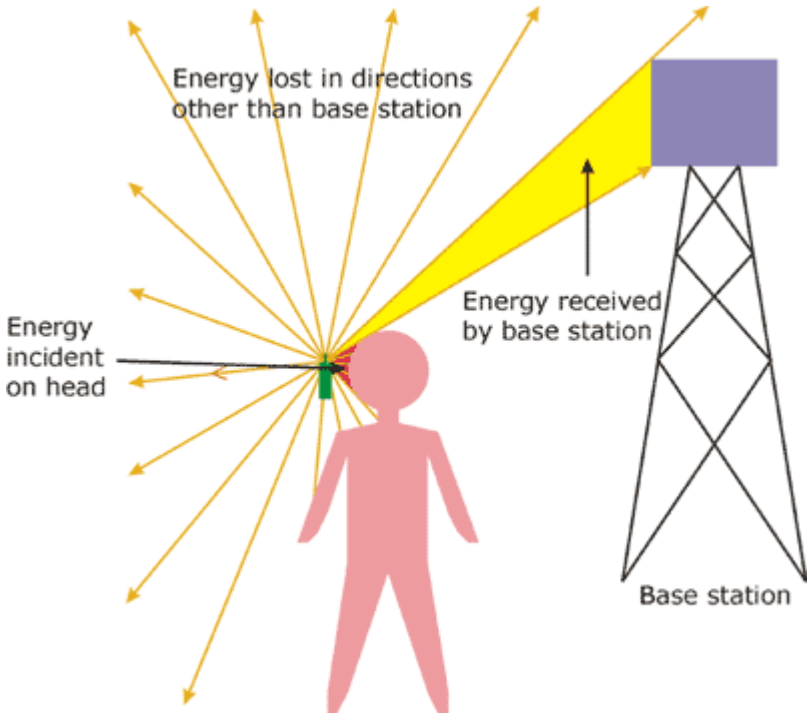
Macrocellular base stations

120 deg sector antennas with microwave tower-to-tower link



Microcellular base station antenna

Cell Phone Handset Antennas



Broadcasting

Phased-array AM Antennas

TV antennas – Sears Tower

4-bay FM station antennas

Radar – Commercial Uses

Radar – Military Uses

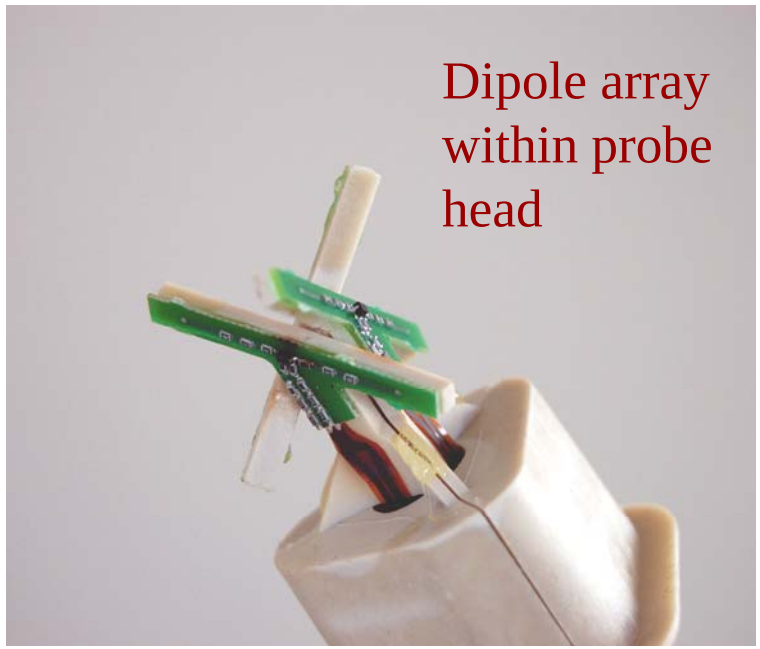
Shipboard phased-array radar

Exposure Assessment

- May use existing evaluations or on-site measurements
- Suggests the use of NCRP Report No. 119
  - *A Practical Guide to the Determination of Human exposure to Radiofrequency Fields*
- Annex D – information on measurement
- Annex E – information on calculations

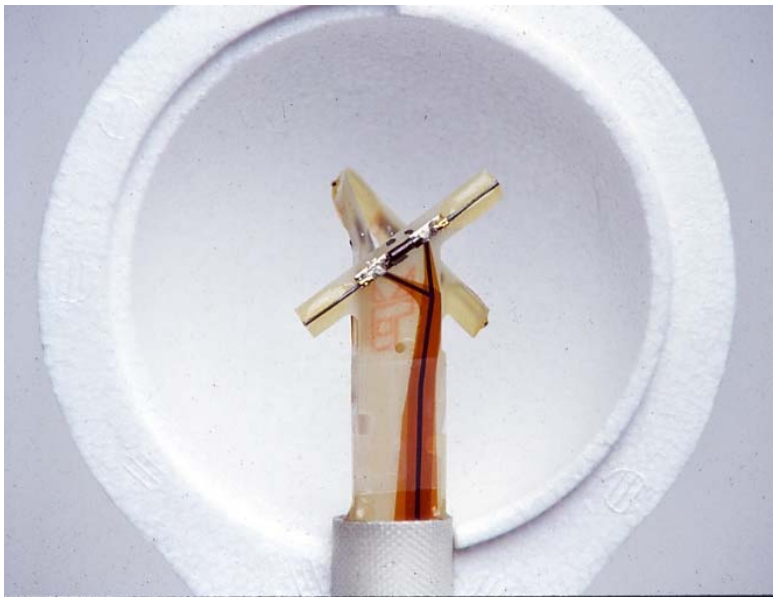
RF Instrumentation

Courtesy: Narda



Courtesy: ETS Lindgren

E & H-field Antennas



E-field antennas: sticks (linear)

H-field antennas: coils

Characteristics of RF Instruments

- Highly isotropic reception pattern
  - Spherical reception pattern
- Broad frequency range
- Flat response across frequency range
  - Exception is shaped-response probes
- Broad dynamic range
- Ability to monitor E & H

Shaped-response Probe

- Sensitivity vs. frequency
  - Inverse of the exposure guidelines
- Uses combination of diode detectors and thermocouples
- Output is percent of standard

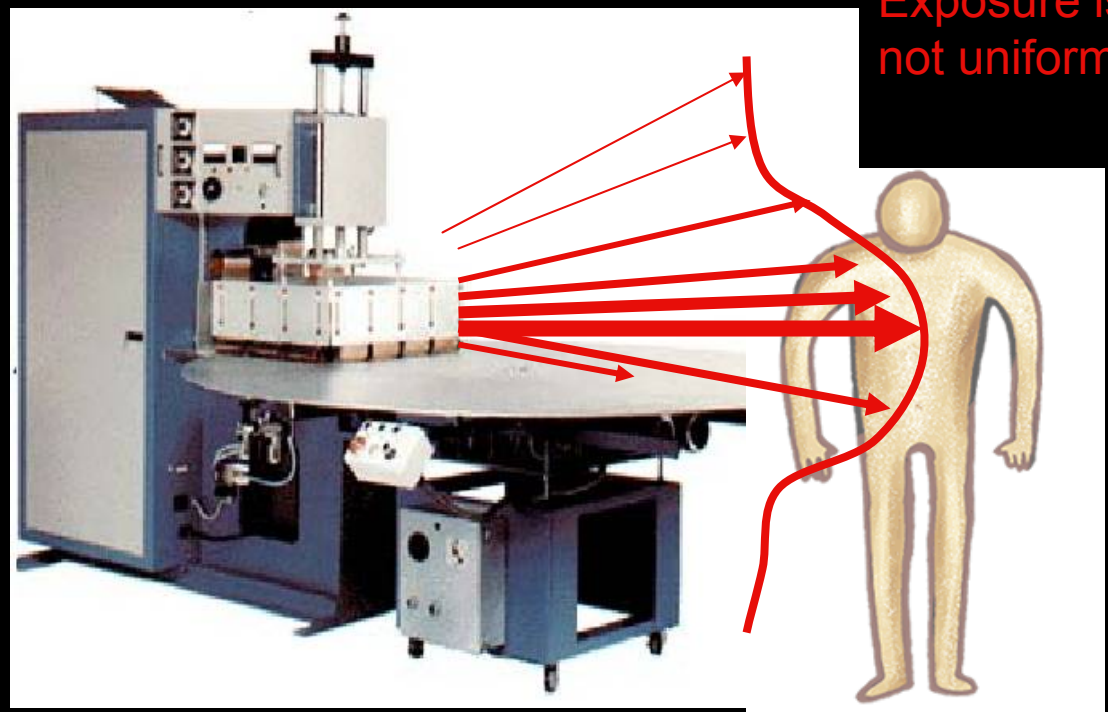
Measurements per IEEE C95.1

- ≤ 30 MHz
  - Measure both E & H fields
- 30 < f ≤ 300 MHz
  - Far field (e.g., intentional radiator): E, H, or S
  - Near field (usu. leakage source): E & H
- > 300 MHz
  - Measure E, H, or S

Measurement: General Requirements

- Determine spatial average exposure
- Determine relaxation for partial-body exposure

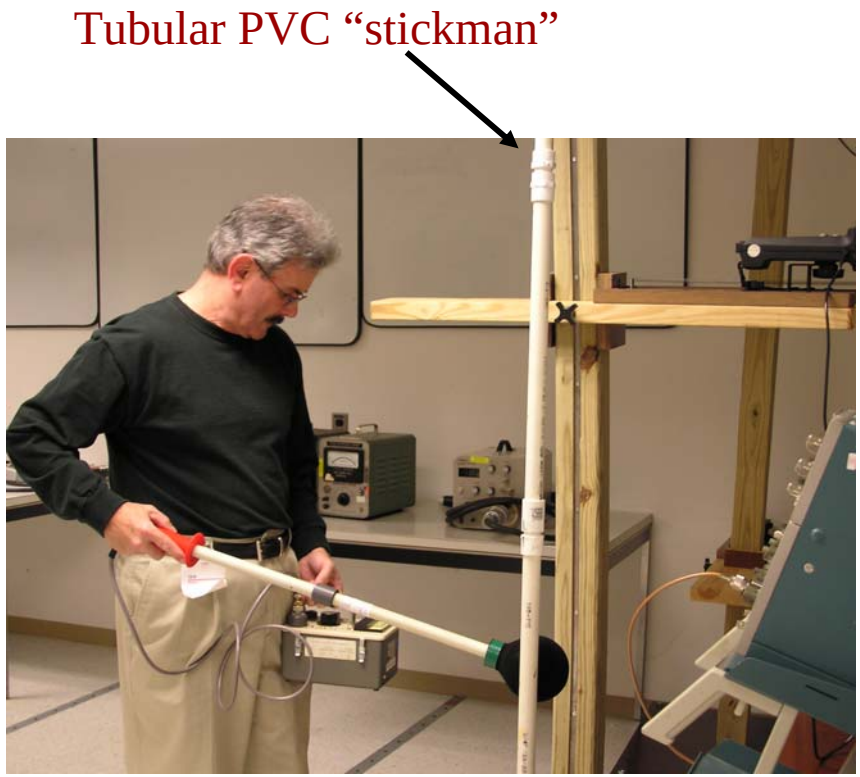
Spatial Averaging



Exposure limit is a WBA, so exposure must be averaged, too

Spatial Averaging

- Use dielectric "stickman" as guide
- Minimum of 10 measurements spaced 20 cm apart between 0 and 200 cm from floor
- Arithmetic average
  - Square E or H
  - Use S as is

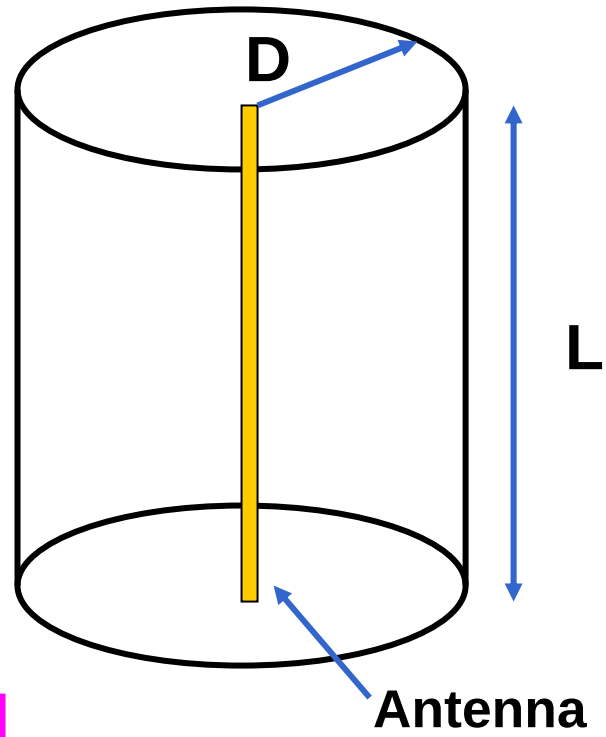


Numerical Modeling

$$S = \frac{P}{2\pi DL}$$

S = power density
(W/m^2 or mW/cm^2)

P = power (W or mW)



Model applies to vertical antenna with horizontal omnidirectional radiation pattern

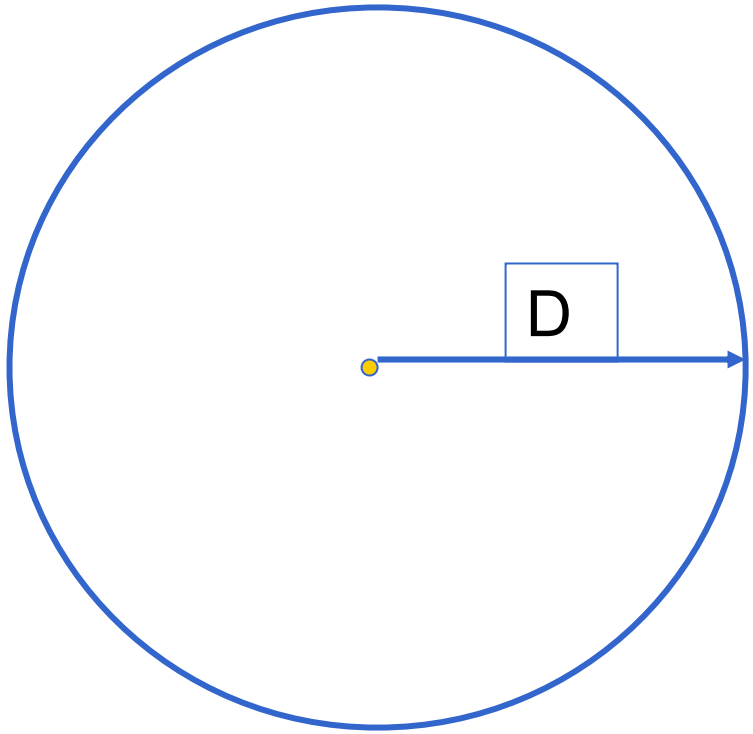
Numerical Modeling

$$S = \frac{PG}{4\pi D^2}$$

S = power density (W/m^2 or mW/cm^2)

P = power (W or mW)

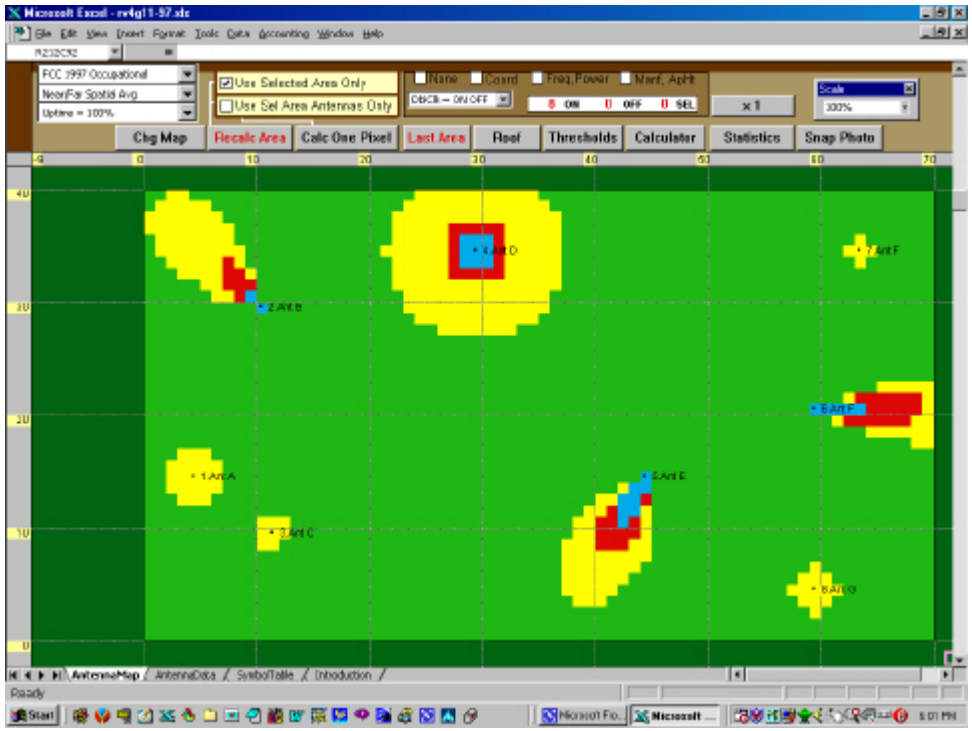
G = absolute gain



Model applies to a point-source emitter with a spherical radiation pattern.

RoofView® Software

Useful for multisignal (multiple emitters) environments



Control Measures

- Dependent upon category
- Summarized in Table similar to ANSI Z136.1
- Includes:
  - Engineering
  - Administrative
  - PPE
  - Training

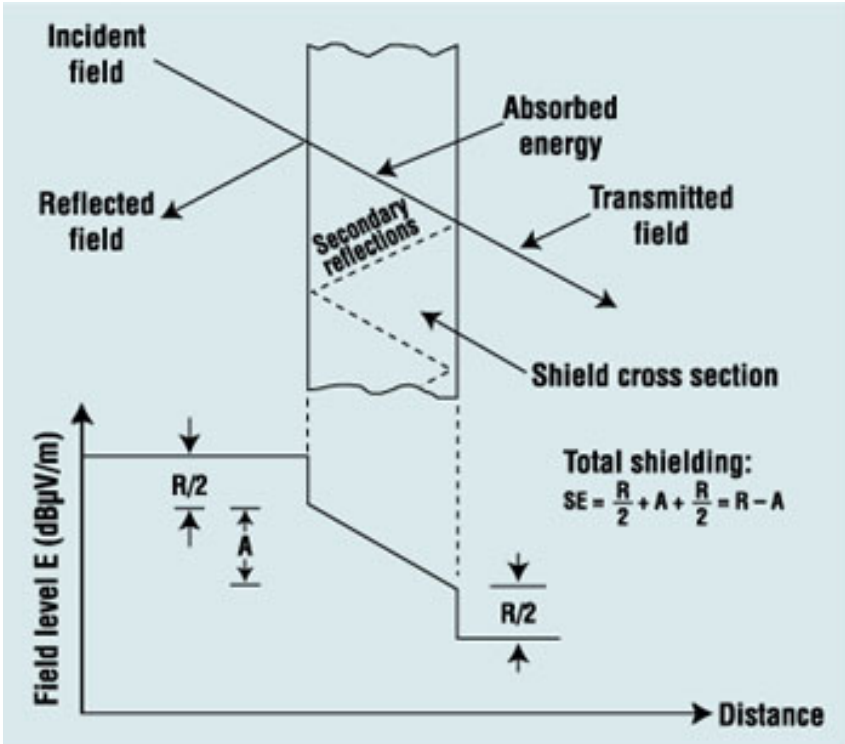
★ Required ✓ Optional — Not applicable

Table 2. Continued.

RFSP Elements	Category 1	Category 2	Category 3	Category 4
4.4 Personal Protective Equipment (PPE)				
4.4.1 Selection of appropriate PPE	—	—	✓	✓
4.4.2 Maintenance and inspection	—	—	✓	✓
4.5 Training	—			
4.5.1 General RF safety awareness	—	✓	★	★
4.5.2 Explanation of RF exposure limits	—	✓	★	★
4.5.3 RF exposure mitigation controls	—	✓	★	★
4.5.4 Possibility of RF interaction with medical devices & implants considerations	—	✓	★	★
4.5.5 Over-exposure incident response	—	—	★	★
4.5.6 Electro-explosive device considerations (when present in the work environment)	—	✓	★	★
4.5.7 Sources of additional Information	—	—	✓	✓
4.6 Program Audit				
4.6.1 Implementation (Program in use?)	—	★	★	★
4.6.2 Adequacy of present program (program audit)	—	★	★	★
4.7 Assess Ancillary Hazards	—	✓	✓	✓

Engineering Controls

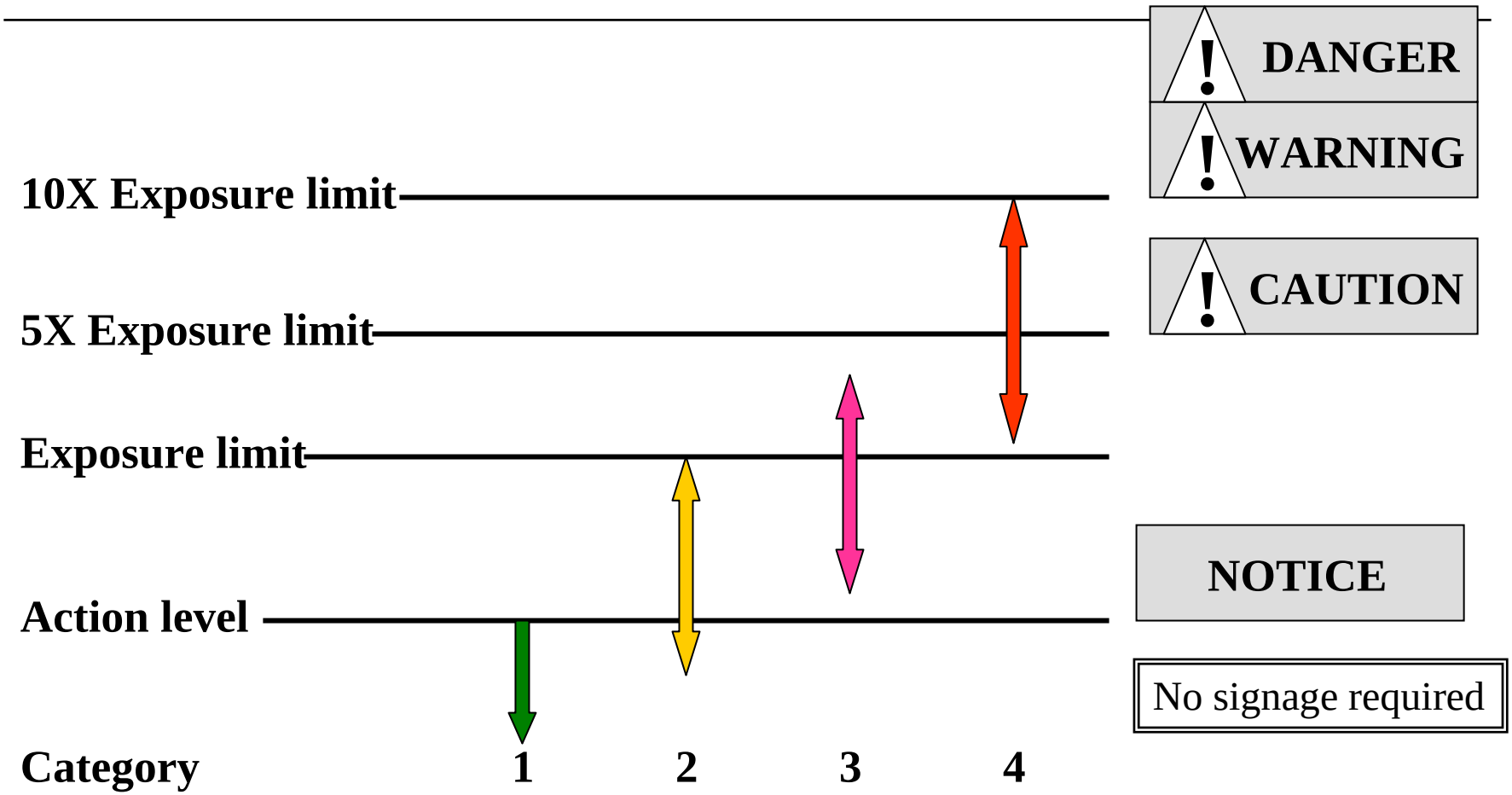
- Configure equipment or site to minimize the potential for exposure
- Use physical barriers to restrict access
- Man-proof barriers & interlocks more effective than administrative controls



Administrative Controls

- Signs
- Work practices
- Lock-out / tag-out
- Reduction of operating power
- Time averaging exposure
- Use of personal or area monitors

Signage & Signal Words



Personal Protective Equipment

Naptex RF protective clothing

- Gloves, overalls, socks, shoes, etc.
- "…care should be used in determining whether RF protective clothing is appropriate in all exposure circumstances."
- Train; inspect; maintain

Training

- “RF safety awareness training is normally the single most important aspect of preventing hazardous exposure to RF energy and is often not sufficiently emphasized in RFSPS.”
- RF safety awareness training should be provided to all individuals who may access areas where RF exposures may exceed OEL
- Annex A lists training elements

Training & Information

- Explanation of RF exposure limits
- RF exposure mitigation controls
- Susceptibility of medical devices & implants
- What to do in case of accidental exposure or RF-related incident
- Annex A lists training elements